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Latest information on the development and application of Voltage/Current Regulated Power Supplies.

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OUTPUT IMPEDANCE MEASUREMENTS

by PAUL BIRMAN, *Applications Engineer*

Output Impedance, for a regulated power supply, is perhaps one of the less well understood characteristic parameters—yet perhaps one of the most important. Because the meaning of an impedance-frequency plot is not widely appreciated, and readily duplicated measuring facilities are not common, this important power supply characteristic is often given secondary attention and is rarely tested.

Load regulation specifications for regulated d-c power supplies can be presented in terms of the internal source impedance, in ohms. If the load is made to vary sinusoidally at an increasing frequency, the value of the load regulation will be observed to change also, because the power supply source impedance is a complex function of load frequency. The output impedance versus frequency specification for a power supply is a way of stating the load regulation for a spectrum of possible load frequencies. It should be noted that the term "impedance" used in this context refers to the *incremental* impedance, not the *matching* impedance, which would be the voltage rating divided by the current rating.

A plot of impedance over a band of frequencies is an important measure of a power supply's regulating ability but is even more significant as an indicator of the supply's a-c stability. Using the Bodé criteria, phase margin and stability can be readily inferred, treating the impedance plot as simply an inverted gain-frequency plot. The impedance is the reciprocal of the feedback gain in the regulating loop.

A properly designed, properly operating, feedback-regulated power supply should exhibit a smooth plot of impedance versus frequency, evidencing an upturn in the impedance at the amplifier's cutoff frequency and proceeding at a 20 db per decade rate with increasing frequency. The location of this 20 db/decade line on a reactance chart (L & C vs. frequency) will be

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NEW BIPOLAR OPERATIONAL POWER SUPPLIES

by PAUL BIRMAN, *Applications Engineer*

The development of the Kepco *Bipolar Operational Power Supply* (BOP) began in 1964 with the introduction of unipolar *Operational Power Supplies* (OPS), and the application of an analog analysis to the description of a power supply's behavior.

By applying the equations and circuit manipulations developed for OP-amps, Kepco engineers found that they could more easily explain—to interested customers—how regulated power supplies could be made to exercise *control* over a voltage or current (rather than simply keeping it constant). Applications grew in the fields of temperature control, illumination, square law multiplications, motor/process control, etc., where the operational explanation for a power supply's behavior encouraged engineers to exercise their imagination in finding rewarding uses for their power control equipment. Rapidly, the concept of an "OP-Amp with muscle" began to take hold, and with the publication of Kepco's *Power Supply Handbook,* in late 1965, prompted Kepco's designers to exploit these properties in operationally designed units.

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A NEW VERSATILE MEASUREMENT SYSTEM

INCORPORATING A KEPCO CK-SERIES POWER SUPPLY

by WILLARD L. ERICKSON and CHESTER V. WELLS, LSR, Inc.

A new approach to training in measurement fundamentals is now available. This systems approach to measurements utilizes versatile consoles. Figure 1 shows a typical console for DC electrical measurements, manufactured by LABORATORY SYSTEMS RESEARCH, INC., of Boulder, Colorado. LSR also offers consoles for AC measurements and combination systems for both DC and AC measurements.

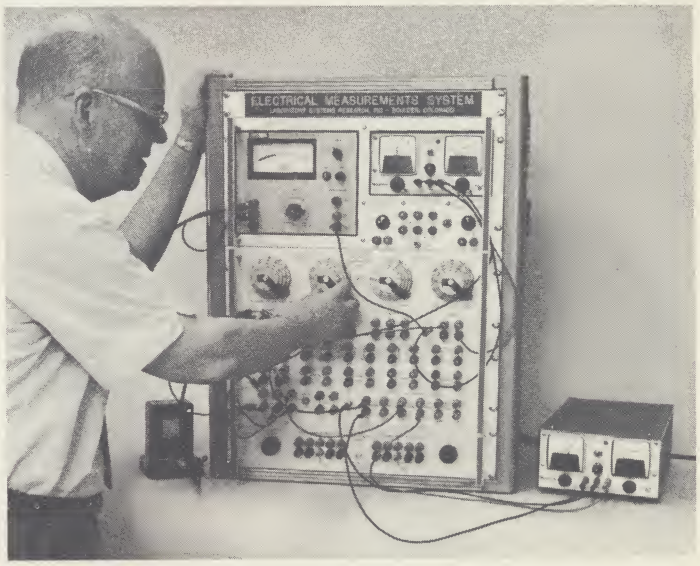

Figure 1: Professor Erickson demonstrates the Measurements System.

These systems can assist greatly in education and training, or in the actual making of measurements and calibration work in the areas of AC and DC voltage and current, resistance and impedance, and in ratio measurements over a wide range of values. The inherent flexibility of this measurement system approach make it particularly appropriate to laboratory training in colleges and universities, industrial and aerospace employee training programs, as well as for junior college and vocational courses.

The heart of the system is the Model 100A Precision Resistive Components Panel, which contains an array of fixed precision resistors, together with two precision decade resistors and two precision Kelvin-Varley voltage dividers, arranged for convenient interconnection with banana-plug leads.

The top panel in the system shown is the LSR Model 402A DC Source and Detector Panel, which provides for close grouping together of a versatile regulated DC Power Supply (Kepco Model CK 36-1.5M, CK 40-0.8M or CK 60-0.5M) and a sensitive Null Detector (Fluke 845-series). In addition, convenient switching is provided for external voltage or current programming and external voltage sensing for the power supply.

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a measure of the value of the source inductance presented by the power supply to its load. As this inductance will be the dominating factor at high frequencies, its value is of considerable importance. Source inductance is specified on Kepco data sheets. The impedance plot should show no bumps or major dips at or near the point of upturn (breakpoint), for these would indicate improper phase compensation and incipient instability. The absence of major irregularities is the most important information to be derived from an impedance test. The *magnitude* of the impedance at any particular frequency (especially high frequencies) is of secondary significance, particularly compared with the effect of series wiring inductance to a real load.

Impedance Measurements, Voltage Regulators:

Several techniques prevail for the measurement of power supply incremental output impedance versus frequency. All involve some method of inducing a sinusoidal current variation in the output circuit of the power supply. An oscilloscope* is used to measure the resultant a-c voltage across the supply's terminals. Dividing this voltage by the driving current gives the output impedance.

One way to vary the load current is to use a sinusoidally modulated electronic load. A precision, noninductive sensing resistor is used to measure the peak-to-peak current. A dual beam oscilloscope permits observation of voltage and current simultaneously. Good four-terminal network practice should be employed, using the power supply's error-sensing terminals for the voltage monitor and the sensing resistor's voltage pick-off terminals for the current measurement.

An alternate procedure employs a wideband power amplifier together with a fixed resistive load to provide the required modulated load. The fixed load is chosen to draw one-half rated load current with an oscillator driving the amplifier to vary the load current (modulate it) above and below the half load level. (A requirement for most regulators is that their terminal current be always unidirectional, as defined by the marked polarity.)

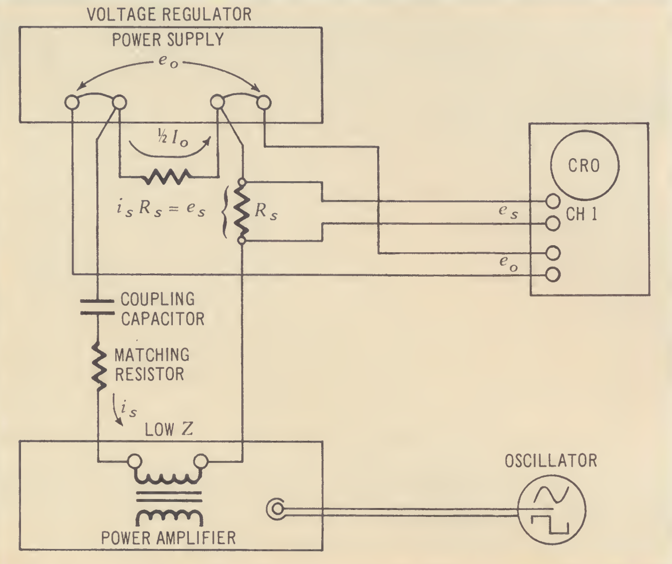

Figure 1: Voltage regulator test circuit for impedance measurement.

To insure that d-c current does not flow in the power amplifier's output transformer winding, an isolating capacitor should be used, together with a matching resistor for the power amplifier. The coupling capacitor must be rated so as to be able to pass continuously the rated peak-to-peak a-c current and have a voltage rating sufficient for the highest voltage power supply being tested. The matching resistor should have an adequate power rating for the chosen modulation level. The amplifier should be used on its lowest impedance tap so that most efficient power transfer to the power supply's circuit can be obtained.

*An osoilloscope is preferred to other a-c measuring devices because of the high ripple rejection ratios possible with human observation of the waveforms.

The amplitude of the modulating current is not important (the measurement is a ratio) so long as the current is sufficient to produce a reasonably large waveform across the voltage-sensing terminals. At low frequencies, this may become difficult to do, particularly if the power supply tested has an exceptionally low output impedance. For example, a one ampere peak-to-peak current is needed to produce a 1 millivolt peak-to-peak signal across a 1 milliohm impedance.

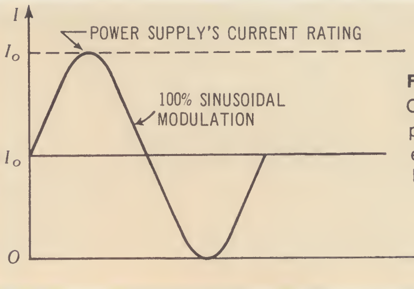

Figure 2: Output current modulation pattern. Current must not exceed Io maximum or be less than 0.

Calculating the Impedance:

Labeling the a-c component across the power supply's terminal e_o, the current-sensing sample e_s, and the sensing resistor itself R_s, then:

$$Z_o = (e_o/e_s)(R_s)$$

If R_s is an even decimal function, like 0.1 ohm, then the ratio e_o/e_s is measured and multiplied by the factor 0.1. The measurement should be repeated at sufficient frequency intervals to permit the drawing of a smooth curve through the frequency range of interest (usually d-c to 100 kHz†). If the results are plotted on log-log graph paper, the slope of the impedance plot near 100 kc can be used to determine the equivalent output inductance. This will, at higher frequencies, dominate the impedance, and once determined, will permit extrapolation of the impedance to higher frequencies.

A typical power supply's inductance will be relatively small—in the microhenry region—necessitating noninductive construction for the current-sensing resistor, R_s. A suggested method of construction is shown in Figure 3.

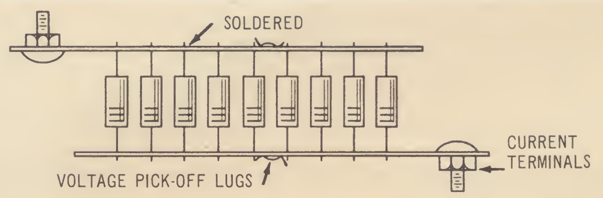

Figure 3: Suggested construction of a low inductance current sensing resistor. 27 parallel 2.7Ω 1 watt carbon resistors sandwiched between two strips of tinned copper. R= 0.1Ω, L≅ 0.01 μH.

Impedance Measurements on Current Regulators:

Output impedance versus frequency is as significant a description of a current regulator's dynamics as it is for voltage regulators. The measuring techniques and results are the dual of the foregoing description for voltage mode. The impedance is high (ideally infinite) and decreases with increasing frequency under the influence of shunt capacitance. It is measured by introducing a series *voltage* modulation. (This compares with the voltage mode measurements, which employed shunt current modulation to measure the low (ideally zero) impedance of a voltage regulator, increasing with frequency as a function of the series inductance.)

Current Mode Procedure:

The basic procedure remains the same as that specified for voltage mode. A modulated load producing—as a function of a varying compliance voltage—a small change in the regulated current which, detected by a sensing resistor, is used to form

†The lowest practicable frequency for which measurement will be possible with this technique will be established by the amplifier's cutoff. A plotting point at d-c can be obtained from the static load regulation measurement.

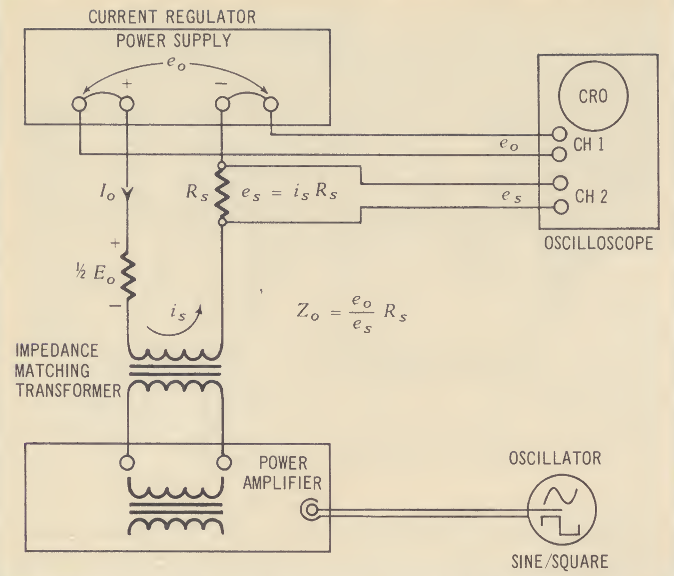

Figure 4: Current regulator test circuit for impedance measurements.

the ratio of a-c components e_o/i_o, defined as the incremental impedance. Plotted versus frequency on full log paper, the impedance will exhibit a 45° rolloff with frequency, characteristic of the output capacitance value. The impedance need only be plotted versus frequency until the slope of the rolloff (and thus the capacitance value) becomes apparent.

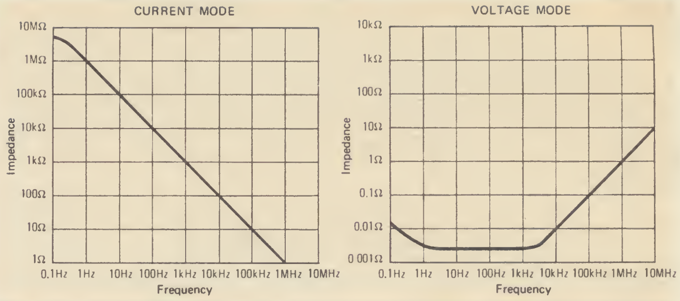

Figure 5: Typical output impedance plot for voltage mode and current mode power supplies.

Conventionally output-filtered power supplies, of course, exhibit a very low frequency rolloff consistent with their large output filter-capacitors. High speed or fast-slewing current regulators with small terminal capacitance exhibit a higher frequency breakpoint.

Paul Birman is Kepco's Application Engineer engaged in the development and marketing of DC regulated power supplies. He is author of the *Kepco Power Supply Handbook* and various magazine articles on the subject of regulated power supplies.
Mr. Birman received his BSEE from the Polytechnic Institute of Brooklyn.

NEW VERSATILE MEASUREMENT SYSTEM *Continued from Page 1*

To make precision measurements over a wide range of values, a common technique employed in electrical standards and calibration laboratories is the use of lead compensation. An LSR Model 151A Lead Compensator is included in the system as the bottom panel in Figure 1.

As originally conceived, these systems would allow the making of measurements as traditionally performed using high quality Wheatstone and Kelvin bridges, impedance bridges and laboratory potentiometers. But, significantly, this approach also allows one to wire up measurement circuits that are found in such modern instrumentation as differential voltmeters, transducer systems or ratio and attenuation measurements systems. Thus one can teach techniques which reflect recent advances in measurement methods, but also can show the historical development of electrical measurements.

The versatility of the systems approach also presents the possibility of exploring finer points of instrument design and/or measurement techniques. A realistic error analysis, with clearly identifiable limits of error, gives options of selecting the method or technique which produces the smallest overall error.

Most measurement accuracies will lie in the 0.01% to 0.1% range. Improved accuracy can be achieved through the use of correction data on the various precision components in the system. Since such precise measurement and calibration work can be accomplished with LSR systems, many small industrial concerns and research projects may find here just the tool to make their most precise measurements and to use in calibration of their common bench instruments. Such measurements can be made traceable to the National Bureau of Standards, if so desired.

Figure 2 gives a close-up view of the LSR Model 402A DC Source and Detector Panel. The Kepco Model CK 40-0.8M Regulated Power Supply serves as the primary DC source and the Fluke Model 845AB is the DC null detector and DC microvoltmeter for the system.

The DC Null Detector-Microvoltmeter has a maximum sensitivity of 1 microvolt end-scale, thus providing adequate sensitivity over a wide range of DC measurements. It can also serve as an excellent DC amplifier for the system, since its recorder output is isolated from the input circuitry.

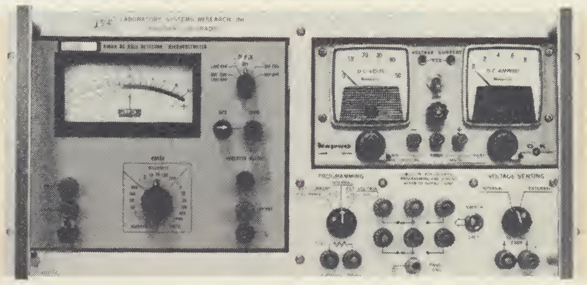

Figure 2. LSR Model 402A DC Source and Detector Panel

The Kepco CK-series power supply, chosen originally for its advantages in a teaching and training situation, carries the same advantages into other measurement applications of the system. Being of the "automatic cross-over" type, the supply may be short-circuited or open-circuited in either its constant voltage or constant current mode of operation without damage to the supply. Additional features were: 1) ten-turn controls for use with precision turns-counting dials; 2) separate voltmeter and ammeter for monitor purposes; 3) "VIX type" mode indication; and 4) remote programming and sensing capability.

The LSR 402A adds to the versatility of the Kepco power supply by providing front panel switching and connection convenience for the resistance programming of voltage or current and external voltage sensing. The precision fixed and decade resistors on the LSR Precision Resistive Components Panel are used for resistance programming the supply.

A double pole-double throw toggle switch is also mounted on the panel with the connections brought out to binding posts. Common uses for this low thermal-emf switch include reversing polarity of the DC source or null detector in bridge circuits.

Voltage and current calibrators, which are particularly useful in determining meter tracking and full-scale accuracy, are quickly formed in this systems approach, as are "diffential voltmeter" circuits.

An example of a series of measurements which are well within the capability of such a DC system are the DC measurements involved with the measurement of performance of another Kepco CK-series power supply. Figure 1 actually shows the set-up for measurement and adjustment of the full-range value

of the voltage mode of the power supply under test, with the measurements being referred to a standard cell. Additional measurements with the same hookup could include the measurement of the stability of the supply with respect to time, the regulation with line and load variations, the linearity of the output with respect to ten-turn voltage control setting, and the determination or adjustment of the resistance programming constant.

As an illustration of the solution of a measurement problem consider the precise measurement of an axial-lead 10-ohm resistor. Such an apparently simple measurement requires careful technique for a precise determination of the resistance value. The unknown 10-ohm resistance is compared in a ratio measurement circuit against a four-terminal 10-ohm resistance standard in the console. The ratio measurement is made with a precision adjustable Kelvin-Varley divider using lead compensation techniques as diagrammed in Figure 3.

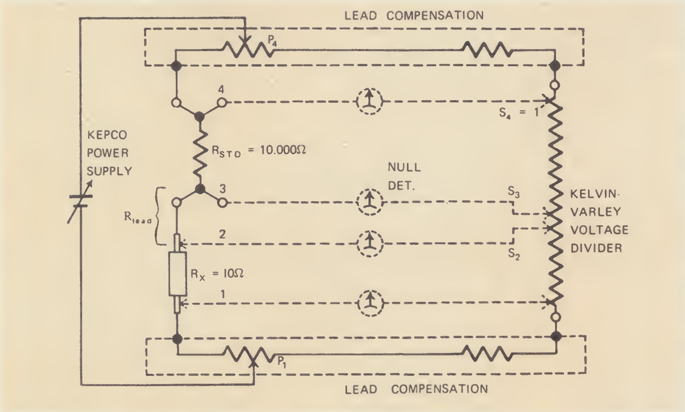

Figure 3.

By making contact to the leads of R_x at the points of actual intended use, marked "1" and "2", and using lead compensation, the resistance of the unused portion of the pigtail can be entirely eliminated from the measurement without cutting the leads.

The null detector is connected between the tap, or output, of the Kelvin-Varley voltage divider and, successively, to the various points marked "1" through "4" on voltage divider formed by R_x and S_{STD}.

A null balance for lead compensation is made, first with adjustable K-V divider at a setting of 0.000 000 and the detector connected to point "1" and adjusting P . Secondly, with the adjustable divider at a setting of 1.000 000 and the detector connected to point "4", P_4 is adjusted for a null. These operations balance or compensate for unwanted lead and contact resistances.

The ratio comparison of the resistors is accomplished by first connecting the detector to point "2" and obtaining a null by adjustment of the K-V divider setting to obtain S_2 (probably slightly less than 0.500).

Then the detector is connected to point "3" and the adjustable divider readjusted for a null, with this setting called S_3 (probably slightly greater than 0.500).

The ratio of resistors, R_X and R_{STD} will have the same value as that of the ratio of the voltage drops across these resistors, or:

The voltage drop, V_{RX} was determined by null balance techniques to be the same as that occurring across the portion of the K-V divider between the settings S_2 and S_1. The voltage drop V_{RSTD}, similarly, equals the voltage drop between S_4 and S_3. Therefore,

$$\frac{R_X}{R_{STD}} = \frac{S_2 - S_1}{S_4 - S_3} \tag{2}$$

The adjustments of P_1 and P_4 (lead compensation) resulted in $S_1 = 0.000\ 000$ and $S_4 = 1.000\ 000$.

Thus equation (2) becomes:

$$\frac{R_X}{R_{STD}} = \frac{S_2}{1 - S_3} \tag{3}$$

Which can be rearranged to

$$R_X = \frac{S_2}{1 - S_3} R_{STD} \tag{4}$$

The effect of R_{lead} was eliminated, but its value can be determined quite precisely as a ratio to R_{STD}. Equation (5) can be derived in a manner similar to that used to derive equation (4).

$$R_{lead} = \frac{S_3 - S_2}{1 - S_3} R_{STD} \tag{5}$$

Typical data taken would yield a value of $R_X = 10.125$ ohms and $R_{lead} = 11.6$ milliohms. If it is desired to make such a measurement at a specific voltage or current through R_X, precision programming of the Kepco power supply can be used to accomplish this.

Error analysis gives the limit of error of the measurement of R_X (based on written specifications) to be 0.02 percent, but actual performance yields errors which are a fraction of this value. This precision is attained because: 1) lead compensation can eliminate the error usually present due to leads between the divider and the low-value fixed resistances; 2) Kelvin-Varley divider readings at points "2" and "3" on the lead can eliminate the error due to the lead and unwanted portion of pigtail; and, 3) four-terminal and pseudo-four-terminal connections eliminate the effect of contact and lead resistances.

The sensitive null detector allows the divider to be read to its full resolution, even with very low power dissipation in the resistances. With the schematic of Figure 3, relatively long leads could have been employed with only small effect on the accuracy.

The authors wish to express their appreciation for the encouragement and comments concerning this article from Mr. Charles Parrish of Kepco, Inc., and Mr. James Hurlbut of J. F. Hurlburt Co. (Denver area Kepco Representative) and to Dr. Kenneth Kupferberg and Mr. Paul Birman of Kepco, Inc., for their technical assistance in the application of power supplies.

These illustrations of the systems approach to electrical measurements and calibration can only begin to indicate the wide versatility of LSR consoles. A textbook, covering both theory and experiment, will soon be available. For further information on these systems and their use, write

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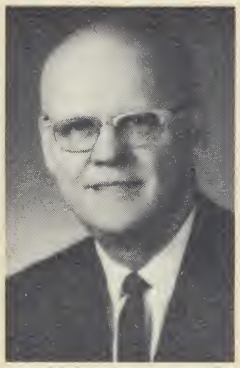
WILLARD L. ERICKSON, President of Laboratory Systems Research Inc. has authored and co-authored several texts in the fields of general physics and electrical measurements during his 25 years of teaching in the Dept. of Physics and Astrophysics at the Univ. of Colorado, Boulder, where he holds the rank of Assistant Professor of Physics and Astrophysics. He has BS (Ch.E.) and MS (Physics) degrees, both from the Univ. of Colorado. He is a member of the Precision Measurements Association and board member of the Central Colorado Section of PMA. He also is a member of the American Physical Society, the American Association of Physics Teachers and the American Society for Engineering Education.



CHESTER .V. WELLS, Vice President of LSR, served three years as an electrical and electronics instructor in the U.S. Air Force and has eight years experience in the design, construction, and maintenance of electronics equipment and systems for instructional laboratories at the Univ. of Colorado. This included the design of a small standards laboratory and calibration consoles for this program. He is currently President of the Central Colorado Section of the Precision Measurements Association. He graduated from Northwest Nazarene College (Nampa, Idaho) with a major in engineering physics.

NEW BIPOLAR OPERATIONAL POWER

Continued from Page 1

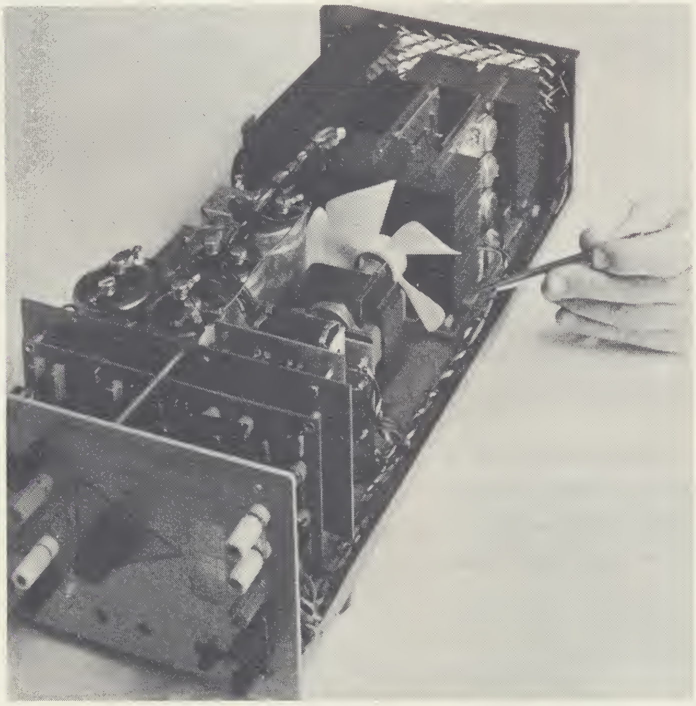
The new units differed from conventional power equipment in three ways:

1. They were actively promoted and used as control – rather than regulating devices. (Even though the actual operation is virtually the same, the concepts are not.)
2. They were given functional panels whose layout and patch board panels were designed to foster a sense of familiarity with the functional aspects of the various control parameters.
3. They were made capable of faster-than-normal "programming speed," or slewing rate. Where a conventional power supply may be limited by its output filter-capacitor to output slewing rates of 250 to 500 volts per second, the new OPS models were designed for speeds of from 500 to 1000 kilovolts per second.

The first of these models was a modest 0–20 volt, 0–50 milliampere amplifier power supply called Model OPS-1A. This was later followed by other "OPS" models, including a 20 watt class "OPS-TA" which was comprised of six models from 0–7V at 0–2A to 0–100V at 0–0.2A. Kepco also introduced a high voltage model capable of 0–2000 volt output at 0–10 milliampere, called Model OPS 2000.

With these new models came a new method for specifying performance. Abandoned, because it was incapable of fully describing the complex performance parameters of an OP-amp, were the traditional "power supply" specs of "regulation." Instead, Kepco adopted the amplifier industry's terminology and test methods for qualifying performance in terms of amplifier "offsets," the small voltages and current found at the ideally *zero* input of the operational amplifier.

In one respect, however, Kepco's "Op-Amp-with-muscle" did *not* resemble a true operational amplifier. They were unipolar . . . that is, they could convey magnitude information but not polarity sense. A number of applications, including the fields of electrochemistry, position control, audio amplifications or X-Y plotting require retention of polarity information which spurred the development of bipolar equipment. The new Kepco BOP 36-5M, a ±36 volt, ±5 ampere model is the product of that development.



Interior view of Model BOP 36-5M showing chassis layout designed for maximum thermal isolation of the OP-amp control circuits (behind front panel). All heat-producing components located in rear area are fan-cooled at 150 cfm, with air drawn in from all sides and blown out at the rear. Power transistors are mounted on finned heat exchangers that are specially designed and have a thermal resistance of only 0.1°C per watt.

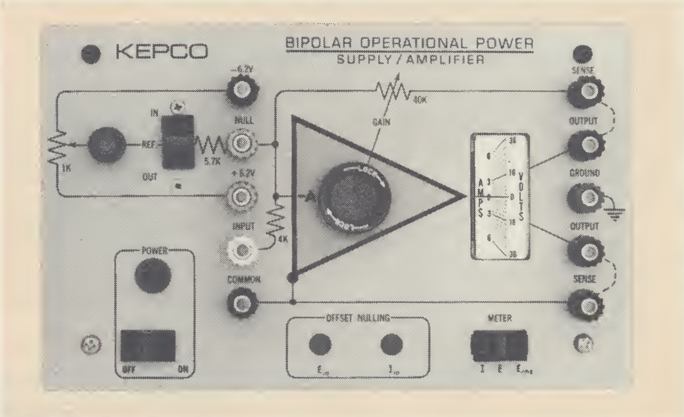
Early in its development, it was decided that the objective would be a power supply/amplifier which could function smoothly through zero with no crossover distortion or nonlinearity. It must be fast (at least 0.5 volts per microsecond) and be capable of operating at any feedback setting, including 100%. A major goal was the development of a controlled roll-off instrument whose input (null) and output terminals could be exposed for external manipulation without restraint.

These goals were met in the Model BOP 36-5 by an amplifier whose critical nodes were exposed on a ten-terminal patch board and which rolls off at a constant 6 db per octave. Internal input and feedback elements were included so that it can be used as a bipolarity power supply, but the elements are easily disconnected, freeing the terminals for external inputs and feedback. An internal switch is provided to give two-speed operation, 4 volts per microsecond for a conditionally stable system — useful except while driving large capacitive loads near 100% feedback, and a 0.4 volt per microsecond speed, which is unconditionally stable for all loads and feedback.

Kepco plans other bipolar supplies in various volt/ampere combinations, largely dictated by market research and customer needs. Kepco is confident that these new classes of instruments will find considerable application in the semi-conductor test industry and as electromagnet drivers, servoamplifiers, anodic/cathodic electrochemical potentiostats, position/speed controllers and audio amplifiers.

With feedback arranged to sense voltage or current, the Model BOP 36-5M functions as a voltage regulator or current regulator – with the *degree* of regulation related to the amount of feedback used. As a voltage regulator, the capacitorless output circuit provides for fast programmability sacrificing only the energy storage which normally limits the amplitude of the transient following fast load changes. As a current source, the high speed characteristics result in a quick-recovery capability. This preserves the ideally high output impedance of the current source *even* under transient changes in the load compliance voltage. With the use of the front panel control bridging the plus and minus reference sources, the output of the Model BOP 36-5M can be continuously varied from plus to minus through zero.

Users response to the functional panel layout has been most gratifying. The concept of a "schematic right on the front panel" eases the transition in thinking from the static to the dynamic notion of power supply behavior.



Model BOP 36-5M Bipolar 180-Watt OP-Amp Power Supply with its schematic front panel, capable of smooth control right through zero from positive voltage to negative voltage with no crossover distortion, delivering rated ±36V DC ±5 amperes continuous duty. The Kepco BOP 36-5M Power Supply is terminated in an operational patch panel, offering complete access to the output, common, null (summing junction) and reference terminals. A variable feedback (gain) control is built-in, though complete freedom of selection is offered the user. A dual plus and minus reference system permits operation as a bipolar power source continuously adjustable from +36 volts to –36 volts, or modulated signals (voltage or current) may be applied up to 20 kHz. Offset voltage and current nulling controls are provided recessed through the panel, for precision adjustment.

For further information, please write for Kepco's new catalog, to Kepco, Inc., Department K, 131-38 Sanford Avenue, Flushing, New York 11352.

KEPCO INTRODUCES A WHOLE NEW DIMENSION IN LOW-COST PRECISION VOLTAGE REGULATORS

The Kepco JQE and CPS Power Supplies embody an approach to power supply design which emphasizes *utility* and *flexibility*.

The basic idea is to build high power laboratory-grade equipment in a fully dissipative format, completely eschewing the use of preregulator, dissipation control devices or circuits. The models in the JQE and CPS lines employ linear series regulators with high-gain, low-offset amplifiers, and good quality reference circuits in a voltage-controlling, current-limiting design.

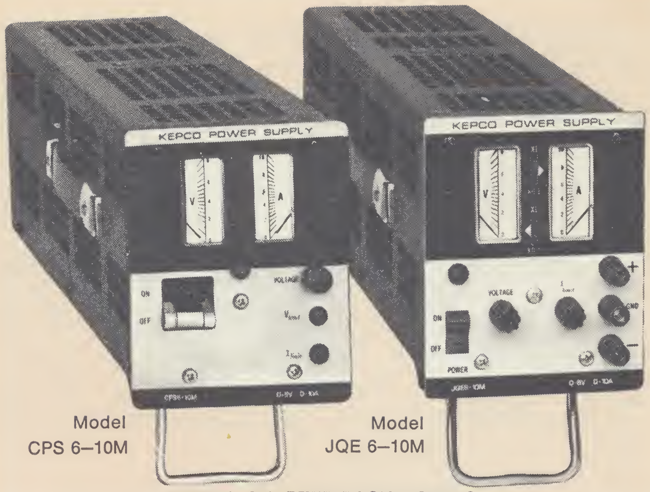
The design approach eliminates RFI-causing SCR preregulators, the bulk and complexity of phase-controlling dissipation limiters, the programming-speed restriction imposed by line-frequency synchronized circuits and results in a *lower cost,* more reliable device.

The fully dissipative approach has been made possible by the development of ultra high efficiency heat sinks which approach 0.1°C per watt thermal impedance. The use of this dissipator allows the removal of large amounts of power with minimum internal temperature rise.

The JQE and CPS series feature 0.0005% line regulation, 0.005% load regulation. Temperature coefficient is 0.01% with an optional low 0.005% per °C temperature coefficient versions available. The JQE series can be ordered with an optional fast programming capability (100,000 volts per second), which also provides quick recovery (10 microseconds per volt) when used as a current regulator.

MODEL	VOLTS	AMPS	STYLE	PRICE
JQE 6–10M	0–6	0–10	1/4 Rack	$289.00
JQE 6–22M	0–6	0–22	1/2 Rack	546.00
JQE 6–45M	0–6	0–45	1/2 Rack	625.00
JQE 6–90M	0–6	0–90	Full Rack	977.00
JQE 15–6M	0–15	0–6	1/4 Rack	289.00
JQE 15–12M	0–15	0–12	1/2 Rack	546.00
JQE 15–25M	0–15	0–25	1/2 Rack	625.00
JQE 15–50M	0–15	0–50	Full Rack	977.00
JQE 25–4M	0–25	0–4	1/4 Rack	289.00
JQE 36–3M	0–36	0–3	1/4 Rack	289.00
JQE 55–2M	0–55	0–2	1/4 Rack	300.00
JQE 75–1.5M	0–75	0–1.5	1/4 Rack	300.00
JQE 100–1M	0–100	0–1	1/4 Rack	300.00

The following optional features can be ordered for the JQE Series: Built-in fast-acting overvoltage protector — Suffix "VP"; high-speed capability (100,000 v/s) — Suffix "HS"; built-in offset voltage nulling control — Suffix "E"; 0.005% per °C temperature coefficient — Suffix "T."



Model CPS 6–10M

Model JQE 6–10M

TYPICAL QUARTER-RACK MODELS

The JQE control loop is fully compatible with Kepco's digital programmers, having available, as an option (Suffix "E"), an integral offset nulling control for precise zeroing. Low offset and extraordinary stability is achieved through the use of a special linear IC control amplifier. This encapsulated unit minimizes the effect of local heating thermal differences that give rise to jitter and short-term instabilities in conventional discrete-circuit designs.

MODEL	VOLTS	AMPS	STYLE	PRICE
CPS 6–10M	0–6	0–10	1/4 Rack	$366.00
CPS 6–10	0–6	0–10	modular	336.00
CPS 6–22M	0–6	0–22	1/2 Rack	613.00
CPS 6–22	0–6	0–22	modular	583.00
CPS 6–45M	0–6	0–45	1/2 Rack	692.00
CPS 6–45	0–6	0–45	modular	662.00
CPS 6–90M	0–6	0–90	Full Rack	1,044.00
CPS 6–90	0–6	0–90	modular	1,014.00
CPS 15–6M	0–15	0–6	1/4 Rack	366.00
CPS 15–6	0–15	0–6	modular	336.00
CPS 15–12M	0–15	0–12	1/2 Rack	613.00
CPS 15–12	0–15	0–12	modular	583.00
CPS 15–25M	0–15	0–25	1/2 Rack	692.00
CPS 15–25	0–15	0–25	modular	662.00
CPS 15–50M	0–15	0–50	Full Rack	1,044.00
CPS 15–50	0–15	0–50	modular	1,014.00

The CPS series features a fast-acting, built-in overvoltage protector. OEM style modules are available without meters.

For complete specifications, write to KEPCO, INC., Dept. K, 131-38 Sanford Avenue, Flushing, New York 11352.

PRINTED MATTER

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Interlocking System Co.
P.O. Box 1546
Poughkeepsie, New York 12603

ADDRESS CORRECTION REQUESTED

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131-38 SANFORD AVENUE • FLUSHING, N.Y. 11352

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